Over the last 30 years, studies of magnetic reconnection have yielded valuable yet limited observational data, and have led to the development of various competing models. Many basic questions about the microphysics of reconnection, the factors that control it, its spatial distribution, and temporal behavior remain unanswered. The SMART instrument complement and orbital strategies described here will allow us to answer these questions, to distinguish between competing models, and to identify new phenomena that are of importance to reconnection in the magnetosphere.

MMS will resolve all of the important spatial scales relevant to the reconnection process. At the electron inertial scale, the four MMS spacecraft will probe the electron diffusion region. At the larger ion inertial scale, the four spacecraft will explore the ion diffusion region where the ions become demagnetized but the electrons are still magnetized. Finally, at the mesoscale, where both the ions and electrons are magnetized and move together as an MHD fluid, the MMS constellation will study force-free flux ropes and plasmoids.

E.1.1.1 What are the kinetic processes responsible for collisionless magnetic reconnection? How is reconnection initiated? Two generic mechanisms have been proposed to explain the demagnetization of ions and electrons that allows the changes in magnetic topology required for reconnection. The first is based on inertial effects [*Vasyliunas*, 1975]; the second invokes scattering due to turbulent electric fields that produce an effective (anomalous) plasma resistivity [*Huba et al.*, 1977]. Here we outline differing predictions of these models and describe the tests we will employ to explore the microscale structure of the reconnection region to discriminate between them.

Does particle inertia control the structure of the reconnection region? Kinetic and two-fluid simulations strongly support the hypothesis that particle demagnetization is linked to inertial scale lengths: c/ω_{pe} for the electrons and c/ω_{pi} for the ions. The detailed structure of the electron and ion current layers that develop at these scales depends on whether the magnetic fields are nearly anti-parallel or alternatively a guide field is present. It also depends on whether there is an ambient density or pressure gradient such as that at the magnetopause (**Figure E-1**), which can break the characteristic field symmetries that are often used as model assumptions.

With a substantial guide field, the electrons demagnetize at a scale length c/ω_{pe}, while the ions demagnetize at the effective Larmor radius, defined by the ratio of thermal speed and cyclotron frequency for species s ($\rho_s = c_s/\Omega_{ci}$) [*Vasyliunas*, 1975]. In this environment, large electron currents in the electron diffusion region are predicted to flow nearly parallel to the magnetic field [*Pritchett*, 2001].

Without a substantial guide field, both electrons and ions demagnetize at scale lengths close to their inertial scales. In this case, the development of non-gyrotropic pressures within the unmagnetized region close to the X-line breaks the frozen-in condition, and the dominant currents close to the X-line flow perpendicular to the local magnetic field [*Hesse et al.*, 1999].

Probing the electron diffusion region poses the following requirements: for typical magnetopause parameters (density of 20 cm^{-3}), the electron inertial scale is 1 km. With a radial magnetopause velocity of 20 km/s, a time resolution of 30 ms will provide two measurements across the electron current sheet. The corresponding ion requirement is 1 s. In the

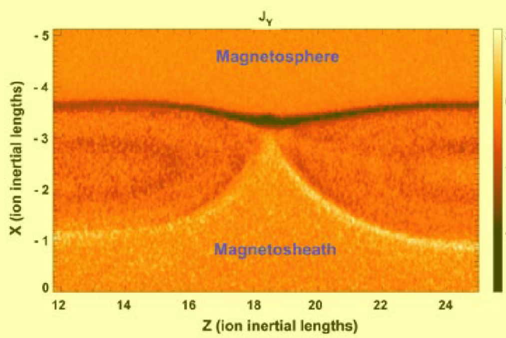

Figure E-1. *Structure of the current layers which develop during collisionless magnetic reconnection at the magnetopause. The figure is from a particle simulation in which there is a drop in the plasma density from the magnetosheath (bottom) to the magnetosphere (top) by a factor of ten. The stronger magnetic field in the magnetosphere causes the magnetic islands to grow preferentially towards the magnetosheath side of the magnetopause, breaking the symmetries often assumed in models and in the interpretation of satellite data. The dominant current layer (the most intense currents are in black) is on the magnetosphere edge of the magnetopause at the location of the strongest jump in magnetic field strength and density.*

magnetotail, where densities are lower and the characteristic scales are therefore larger, less time resolution (100 ms for the electrons) is needed but a larger energy range is required (10 eV-20 keV as opposed to 10 eV to a few keV at the magnetopause).

The multi-point SMART particle measurements, in conjunction with high-time-resolution electric and magnetic field data, will enable us to compare **E** × **B** drifts with measured flows to determine accurately the locations where both species are demagnetized to obtain a definitive picture of the structure of the electron and ion diffusion regions. Measurements with the ion composition instrument will determine whether the heavy ions decouple from flows at greater distances from the X-line than lighter ions, as predicted by theory. Measurements of diffusion-region widths different from those predicted by the inertial model will indicate that other processes (possibly including anomalous resistivity) are active.

In the inertial reconnection model, the peak speed of dispersive kinetic Alfvén and whistler waves controls electron flows from the inner region of the diffusion region [*Rogers et al.*, 2001]. Evidence for the quadrupole Hall magnetic fields from these waves has now been found in satellite encounters with the diffusion region [*Øieroset et al.*, 2001; *Nagai et al.*, 2001]. Since the predicted electron outflow jets have characteristic widths comparable to c/ω_{pe}, the instrument requirements for measuring them are similar to those for measuring the width of the electron inertial zone. High-time-resolution electric and magnetic field data, combined with electron density and flow measurements, will enable a comparison of the local wave properties with measured flows.

Can wave turbulence produce anomalous resistivity to drive reconnection? Strong electric and magnetic field fluctuations are common in the guide-field configurations that occur in the magnetopause current layer [*Anderson et al.*, 1982; *Tsurutani et al.*, 1989]. In addition, recent measurements from WIND [*Farrell et al.*, 2002] revealed the existence of strong electron plasma waves at the upper hybrid frequency on field lines connected to the diffusion region. Particle simulations confirm that strong currents, which develop during guide-field reconnection, produce high-frequency waves [*Drake et al.*, 2003]. Buneman instabilities collapse into bipolar regions of intense parallel electric field, electron holes, or electrostatic solitary waves with structures consistent with observations [*Cattell et al.*, 2002]. Scattering of electrons from the holes may produce a strong anomalous resistivity, thereby enabling the dissipation required for magnetic reconnection. Insufficient time resolution for electron distribution functions currently precludes establishing a causal linkage between electric and magnetic field observations of electron holes and particle measurements of local electron beams. The SMART instrumentation will provide the required simultaneous observations on suitable time scales, namely 25 ms for the electron distributions and 0.1 ms for the electric and magnetic field measurements.

Are thin current sheets necessary for the onset of magnetic reconnection? The onset of fast magnetic reconnection requires a thin current sheet. Observations provide evidence for embedded current sheets with thicknesses of the order of an ion gyro-radius [*Fairfield*, 1984] or smaller [*Mukai et al.*,1996]. Double-peaked current sheets have also been measured [*Hoshino et al.*, 1996]. However, questions as to how thin current sheets form and how they facilitate magnetic reconnection remain unclear. Sufficiently strong enhancements of the current density may depress normal magnetic fields and thus electron magnetization sufficiently to trigger reconnection [*Hesse and Schindler*, 2001]. SMART multi-spacecraft and high-time-resolution measurements, at the same scales as for the electron diffusion region, will provide the temporal and spatial resolution required to resolve the current layers, identify current carriers, and thus determine the mechanism of electron demagnetization at the onset of magnetic reconnection.

Closure: What are the kinetic processes responsible for collisionless magnetic reconnection? Distinguishing between competing mechanisms for the breaking of the frozen-in flux condition—and in particular, establishing whether small-scale turbulence or laminar kinetic processes dominate—requires in situ measurement of electron distributions and magnetic and electric fields in the electron diffusion region. The exact size of this region is not known and depends on the dominant diffusive process. For inertia-based processes, the thickness of the electron diffusion region is ~1 km at the magnetopause and ~10 km in the tail. The SMART orbital strategy will be designed to maximize encounters of this small region.